Electronic Health Records: Improvement to Healthcare Decision-making

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***Abstract*— Effective decision-making plays an important role in promoting optimal care delivery. Factors such as availability of data, timely access to data and organised information greatly influences the quality of decision-making as illustrated in a causal loop diagram. The contribution of practice-based evidence thus aims at structuring an approach where healthcare professionals can be consistently assisted in making effective decisions during routine primary care. Through a practice-based evidence e-health scenario and a data-flow diagram of clinical systems in a public hospital from Singapore, we have identified the importance of leveraging electronic health records as ideal resources in the pursuit of improving healthcare decision-making.**

Keywords*— data warehouse, decision-making, electronic health records, evidence-based practice, ICT, practice-based evidence

I. INTRODUCTION

Making effective and accurate decisions is a crucial attribute in any industry and, healthcare decision-making is no different. In particular, healthcare and associated clinical decisions are critical, as they are highly dynamic and complex [1]. Through quality decisions that are made, clinical care delivery can be more effective [2] and has the potential to positively and progressively improve patients' health outcomes, be cost-effective and provide care in a much safer manner [3]. With healthcare professionals such as clinicians, doctors, nurses and healthcare service providers routinely facing critical clinical situations, there are constant demands to make effective decisions. Compounded by issues such as increasing prevalence in patients with chronic conditions, the increasing aging population and surging healthcare expenditure and costs, the ability to make well-informed decisions will potentially enable healthcare organisations to further improve the quality of care and management of their patients.

The use of clinical information systems, such as electronic health record systems (EHRs), computerized physician order entry (CPOE), laboratory information systems (LIS) and clinical decision support systems (CDSS) within healthcare organisations have become essential mechanisms in the effort to improve the delivery of healthcare services to patients [4]. Improvements in the health of patients [4, 5], and reduction in medical errors [5, 6] and healthcare costs [4-6] are some benefits arising from information and communication technology (ICT) adoption. Other studies however have argued that the total benefits arising from the adoption are still minimal. Issues such as financial constraints, temporary loss of productivity and, privacy and security concerns [7] were cited as reasons and barriers to ICT adoption. While such concerns are legit especially for small to medium sized healthcare organisations, it still should not be the main reason for not adopting ICT in the long run. As such, new approaches have to be developed where the benefits can further outweigh these concerns. One such approach is the practicability as a theory of Practice-based evidence (PBE).

Through the adoption of ICT, massive collections of digital health data or electronic health records (EHR), which contain valuable health and healthcare related information, are generated. These collections of digital health data represent an enormous opportunity where information recorded by healthcare professionals during actual clinical practice and captured in EHR can be further researched and analysed to aid in improved decision-making. Besides leveraging on healthcare professionals' inherent medical knowledge and experiences, the availability of information and data that can be acted upon, further improves their ability to make better and quality decisions. Thus, in the theory of the Practice-based evidence approach, the utilisation of EHR is a major key component.

It is also important to note that the availability of data, information or evidence does not necessarily translate to effective decision-making. Instead, findings from analysis of such collections become resources and evidence for healthcare professionals to consume in the process of decision-making. For example, secondary uses of electronic health records to support research findings are well published in leading journals and conference articles. Some of this research capitalises on the information captured in EHR such as, discovery of disease correlations, disease-drug knowledge, medication use, clinical recommendations and stratification of patients. In other studies, EHR has been used to enable the identification of patients with suspected conditions such as diabetes or atrial fibrillation. Such findings exemplify the huge potential in the secondary use of EHR. Therefore, its use in the discovery of new clinical and medical findings is strongly recommended as it has the capacity to help healthcare professionals make better decisions.

Leveraging on the findings from EHR for the approach of PBE are factors that can positively influence the quality of decision-making, especially when the paradigm of Evidence-based practice (EBP) is currently facing some challenges.

Adopters have already questioned the effectiveness of EBP in directing the practice of medicine. With limitations such as difficulty in effectively applying evidence to actual real world patients, the relevancy of EBP becomes a concern. This in turn affects the quality of care that can be provided. However, this is an opportunity where an approach such as PBE can complement such a limitation. Besides improving decision-making capabilities, PBE is able to provide relevant and reliable evidence in a timely manner that can be easily applied to individual patients, thus resulting in patient-centered care.

Therefore, the goal of this study is to introduce the concept of Practice-based evidence and investigate the implementation of such an approach on an existing ICT infrastructure of a public hospital system in Singapore. Through the use of a data-flow diagram, understanding the flow of data from multiple clinical systems in place within the healthcare organisation and the type of information that is captured in electronic health records is useful. This will enable us to understand how EHRs can be utilised as practical clinical evidence for PBE.

II. Decision-making in healthcare

Decision-making is both a complex and complicated process that healthcare professionals go through on a daily basis. It places great pressure on them to make effective decisions based on what little resources are available. At times, it is also stressful for healthcare professionals to make the best decision possible in this highly dynamic and complex healthcare industry.

Despite the difficulties in making effective decisions, it is important to realize that the healthcare industry should not be allowed to accommodate to, and tolerate any level of ineffective decisions. Patients expect to be provided with the best care possible, which often than not, can be achieved through effective clinical decisions. With all forms of care concerns the life and health of patients, it is imperative that healthcare professionals be constantly equipped with the tools and resources to consistently make well-informed clinical decisions. In the pursuit of providing the best care possible for patients, the ability to make effective clinical decisions becomes a critical element. Hence, we need to look at factors, which influence decision-making processes and how improvements can be made to the quality of decision-making.

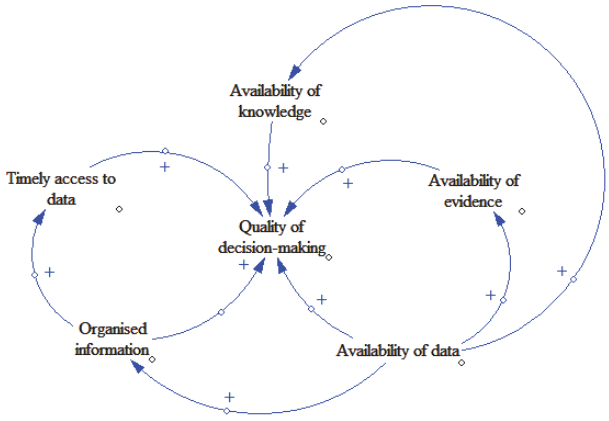

Fig. 1. Factors affecting the quality of decision-making reflected in a causal-loop diagram

There have been several studies which investigate the factors that influence the quality of decision-making. For example, in two separate studies, one by Akyürek, et al. [1] and by Tunis, et al. [8], the availability of knowledge, data and evidence are found to be factors which play crucial roles in the improvement of the quality of decision-making. Equally important, is having timely access to health and medical data, and access to information which is well organised. Although, healthcare professionals would naturally gain knowledge through work experiences, practices and training, having additional resources such as online medical literature and publications will substantially aid the improvement in knowledge as well. Thus, such improvements may influence the quality of decision-making.

Therefore, based on the findings from the studies above, we are able to visualize the interrelationship between the factors and how it interacts with each other to further improve the quality of decision-making, via a causal loop diagram as depicted in Figure 1. It shows how the factors have a positive reinforcing effect towards increasing the quality of decision-making. Hence for the approach of PBE to have a similar influence, that is to improve the decision-making capabilities of healthcare professionals, the same factors can therefore be adopted in PBE. With the readily available collections of electronic health records, it represents the reliable source of data, knowledge or evidence as suggested by the causal loop diagram.

III. Practice-based evidence

Clinical practice has long been supported by the paradigm of Evidence-based practice. This has resulted in a methodological approach to treatment such as, through the use of clinical guidelines; it allows healthcare professionals to make better decisions regarding appropriate treatments and medications. It has also evolved clinical practice to be "more scientifically and empirically grounded" enabling patient care to be safer, consistent and cost-effective [3]. However, significant limitations of EBP have prompted healthcare professionals, researchers and academics alike to consider alternative or complementary approaches to the delivery of care to patients instead. Thus, the concept of the Practice-based evidence approach.

The approach adopted by Practice-based evidence is not to displace Evidence-based practice. Instead, its objective is to complement the findings from EBP and improve decision-making by providing clinical evidence from doctors' practices captured in electronic health records. Documentation of doctors' clinical practices, which may have been directed by the use of clinical guidelines or systematic research, into an electronic health record is an affirmation that the care provided has been appropriately and correctly thought of. Thus, the details captured in electronic health records can be adopted as practical clinical evidence, which can be used to direct and assist other doctors when making decisions.

As aptly put forth by Barkham and Margison [9], Practice-based evidence is "*the conscientious, explicit, and judicious*

use of current evidence drawn from practice settings in making decisions about the care of individual patients. Practice-based evidence means integrating both clinical expertise and service-level parameters with the best available evidence drawn from rigorous research activities carried out in routine clinical settings". As such, EHR truly represents the evidence of activities carried out in routine clinical practice, which can be further illustrated in the following scenario.

A. Practice-based evidence e-health scenario

Figure 2 illustrates a process involving a doctor and his patient during a routine consultation. It illustrates how practical clinical evidence is captured in an electronic health record. Whenever a doctor prescribes a medication and orders a laboratory test or indicate his clinical findings in the clinical notes, valuable clinical information is being captured in the health record. The collection of such information in electronic health records thus becomes clinical evidence of one's practices that can be used to discover new findings regarding treatments, medications, clinical tests and so on.

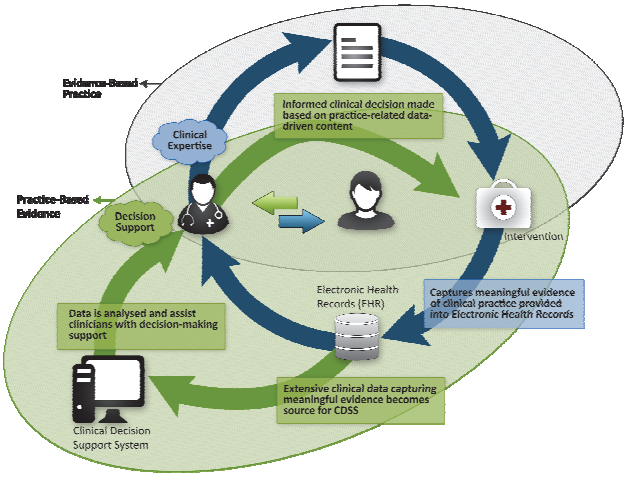

Fig. 2. Scenario of practice-based evidence improving doctor's decision-making capabilities [10]

Consider the following scenario. A patient, Adam, suffers from diabetes and hypertension, and has adverse drug allergies to metformin and insulin. In order to treat his diabetic condition, his doctor, Henry prescribes a new medication 'X', as described on a new clinical guideline he comes across. Doctor Henry documents Adam's drug allergies and orders medication 'X' for him. A few days later, Adam returns to complain that he has developed a rash after taking the new medication. Doctor Henry decides to stop the medication and order an allergy test for Adam. As it turns out, because Adam has been taking Antenolol as well for his hypertension, it has reacted with the new medication 'X' resulting in him getting the rash. Doctor Henry captures his findings in the clinical notes and after researching other clinical guidelines, prescribes Adam with a new medication 'Y'. Medication 'Y' is ordered and captured in Adam's electronic health records. Adam has had no further allergic reaction to the new medication and both his chronic conditions are being managed effectively.

Meanwhile, Doctor James, from the same healthcare organisation as Doctor Henry, is visited by a new patient, John who also suffers from diabetes and hypertension, and has an allergy to insulin. In a Practice-based evidence scenario as depicted in Figure 2, the information and data from all the patients' electronic health records are integrated and fed into a decision support system where it is analysed and adapted to provide assisted decision-making based on John's medical condition. Through this approach, Doctor James is then alerted to the possibility of prescribing John with 2 new medications to treat his diabetic condition, medication 'X' and 'Y'. He is also alerted that since John is also on Antenolol, it is advisable to prescribe medication 'Y' since there is evidence that medication 'X' has a drug-drug interaction with Antenolol. That evidence is presented based on the existence of information captured in Adam's health records. Without the approach of Practice-based evidence, Doctor James would have to spend more time finding suitable clinical guidelines that is applicable to John and would not have found out the drug-drug interaction medication 'X' has with Antenolol.

B. Data flow diagram enabling practice-based evidence

In Practice-based evidence, the utilisation of electronic health records as practical clinical evidence is a critical component of its approach. Illustrated in the previous PBE e-health scenario, valuable data regarding patients' health and healthcare related information are electronically captured in electronic health records. Through data analysis and analytics, EHR provides healthcare professionals and researchers with

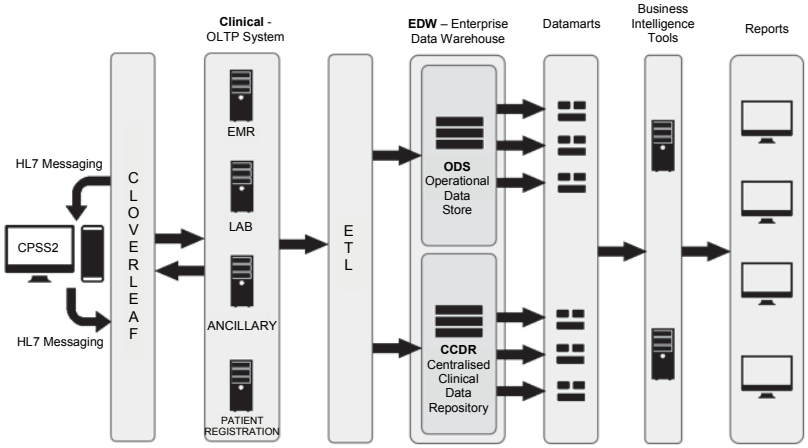

Fig. 3. ICT infrastructure of one of Singapore's public hospitals

additional information that can be used to uncover new findings and help to improve the overall patient care.

To understand how EHR can be utilised as practical clinical evidence for the approach of Practice-based evidence, we studied the flow of data from multiple clinical information systems within a public hospital in Singapore.

In an initial study to understand the ICT infrastructure of one of Singapore's public hospitals, we discovered the extent to which clinical information systems were implemented and envisioned how the architecture would be like. In Figure 3, an in-house bespoke integrated electronic medical records (EMR) systems called CPSS2 (Computerised Physician Support System 2) is a single interface where all relevant clinical information from multiple systems such as patient registration, medication management systems and, laboratory and radiology imaging systems [11, 12] are displayed. As the clinical information comes from different clinical systems, the data sources are tightly linked up through a system called CLOVERLEAF, which sends and receives HL7 messages to and from CPSS2.

Based on this study, the existence of 2 enterprise data warehouses; Operational Data Store (ODS) and Centralised Clinical Data Repository (CCDR) represents the readiness of the infrastructure to implement the Practice-based evidence approach. ODS, in this case, holds mainly operational data such as financial, patient registration and some portion of clinical data. The CCDR holds all clinical data such as prescription data, laboratory results, radiology results, OT (operating theatre) reports as well as patient demographics. As such, the CCDR represents an ideal data source to implement the Practice-based evidence approach as illustrated in the previous scenario. This is further envisaged in a data-flow diagram.

By visualizing the flow of data in a data-flow diagram based on the illustrated PBE e-health scenario, we were able to find out which clinical information has been documented and captured in an electronic health record. In the following data-flow diagram depicted in Figure 4, it shows the processes that may have taken place during a routine doctor's consultation and the flow of data from an individual clinical system's datastore. For example, when a medication order request is made, a HL7 message is sent to the eIMR. The request is capture in the EHR and corresponding data is loaded to the eIMR datastore as an entry. Next, the data from each datastore is extracted, transformed and loaded into the enterprise clinical data warehouse. This data flow is then repeated by all doctors for all patients throughout the healthcare organisation. The data warehouse will by then have contained integrated health and healthcare related information of every patient.

The approach of Practice-based evidence continues from the data warehouse. The data warehouse provides healthcare professionals with a complete picture of a patient's full medical condition. In addition, since the data warehouse already contains information about all patients, analytics and statistics can be performed on it to provide healthcare professionals with additional organisation-wide knowledge as well as potentially new information. New findings can be discovered through analysis, such as the recommendation of an alternative medication as illustrated in the PBE e-health scenario earlier. For example, integrated patient clinical information from the data warehouse can be extracted using data marts and analyzed using business intelligence (BI) tools. Based on the medical characteristics and demographic of the particular patient that is being consulted by the doctor, data mining and analytics tools can be utilised and helped to discover relevant information that can be applied to the patient. As a result, the approach is tailored to care for individual patients.

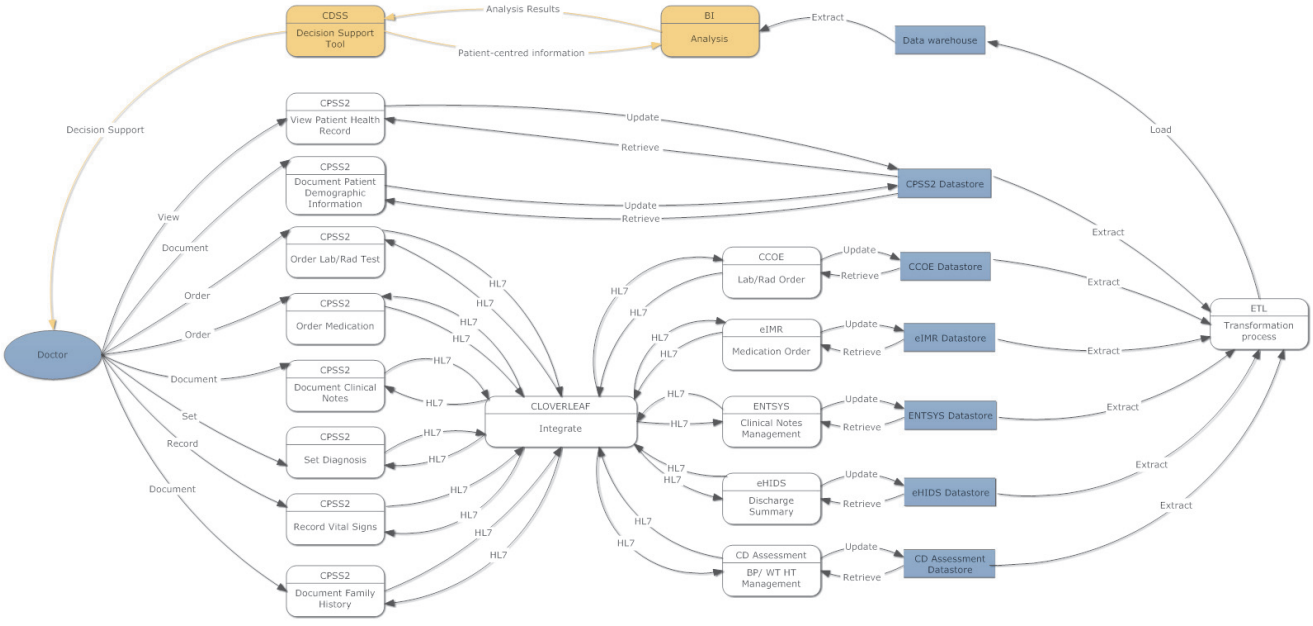

Fig. 4. Data flow diagram enabling a practice-based evidence approach

While the above scenario may seem theoretical, we have noted that there have been numerous research studies which demonstrate how electronic health records can potentially be used to assist and improve healthcare delivery. Secondary uses of EHR have shown to be able to improve the detection and screening of type 2 diabetes [13], improve identification of patients with heart failure [14] and predict condition severity of congestive heart failure patients [15]. More often than not, such studies have been conducted within a research capacity to investigate EHRs' potential capabilities, but hardly been leveraged as evidence or additional analysed information, forming part of healthcare professionals' decision-making process. Hence, it is an opportune time for EHR to be used as practical clinical evidence as part of routine primary care which can be realised through the approach of Practice-based evidence, as depicted in Figure 2 and 4.

With the paradigm of Evidence-based practice facing challenges in its capabilities of applying evidence to actual patients, Practice-based evidence thus complements it and improves care by being highly relevant and applicable.

C. Implementing the PBE approach for diabetes

As we have highlighted, the approach of Practice-based evidence utilises the large collection of electronic health records, which contain practical clinical evidence, to assist healthcare professionals make well-informed decisions. Thus, the key requirement to the adoption is enabling the availability and accessibility of these electronic health records. With healthcare organisations frequently implementing many stand-alone clinical information systems to meet individual department needs, integrating the data sources to get a complete patient health and healthcare related information is a challenge. With the advancement in ICT, one of the most common yet effective ways of integrating the data sources from disparate systems is through the technique of data warehousing.

As we saw in Figure 2, the implementation of a data warehouse suggests that the integration of the data sources from multiple clinical systems has been achieved. This simplifies the implementation of the PBE approach with a readily available data warehouse implementation. If a data warehouse was not implemented, the typical process of building any data warehouse begins with the cleaning of source data. Data from different clinical information systems are cleansed from any erroneous information. This can be done with the help of medical experts who have the domain knowledge with regards to the correctness of clinical information. Next, is the Extraction, Transformation and Load (ETL) process. In the extraction process, the cleansed data sources from multiple systems are extracted. These data sources are then transformed to match with the schema of the target system, which is the data warehouse. Finally, the transformed data is loaded into the data warehouse and is now ready for analysis. The benefits of a data warehouse besides integrating many different data sources into one, is also to facilitate real-time analysis [16], which is a key feature of Practice-based evidence.

When a data warehouse is loaded with complete patient health and healthcare related information, healthcare professionals and researchers are able to perform numerous analyses, analytical and statistical studies. For example, based on the scenario illustrated in Figure 2, analysed data from the data warehouse can be used to inform healthcare professionals with effective medication recommendations. Alternatively, analysis of EHR can also be used to predict or identify patients who may be at risk of diabetes.

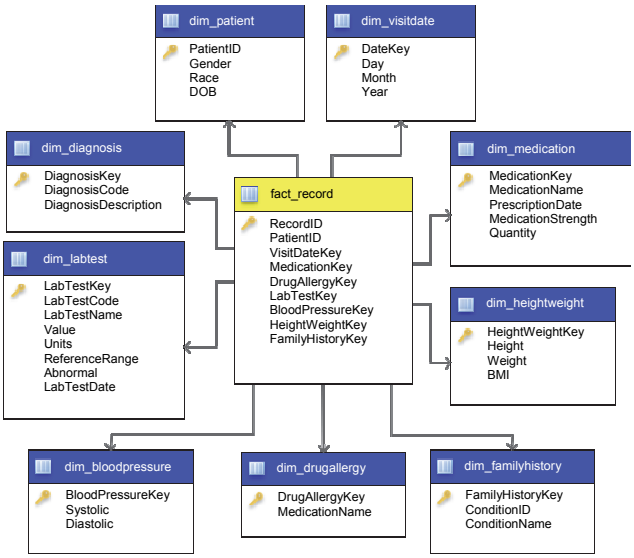

Fig. 5. An example of a star schema for a diabetes data warehouse

Following the building of a data warehouse, the next step is to get the relevant data out from the data warehouse for analysis. Therefore, a dependent data mart (DDM), which represents a subset of the data warehouse, is used to extract the required data from the data warehouse [17]. Figure 5 represents an example of a data mart with a star schema. A star schema consists of a fact table, with each entry in the fact table corresponding to a particular dimension. For example, the PatientID entry links to the dimension table called "dim_patient" with the data types gender, race and date of birth. Every dimension table is linked to the fact table via a foreign key relationship.

Using this data mart design, clinical information associated with all known diabetic patients are extracted. Data mining techniques such as logistic regression or decision trees can be applied to this extracted data to reveal hidden patterns and trends. Additionally, similar techniques can be applied to perform prediction analysis. For example during a primary care encounter, prediction analysis can help healthcare professionals identify the probability of the consulted patient being at risk of diabetes. This can be achieved if proper analytics techniques are being implemented. For instance, in an evaluation study conducted by Anderson, et al. [13], the use of random forest prediction models on a sample EHR dataset showed positive results and a high predictive accuracy of diabetes status among patients. The study also revealed that when using a full EHR model, such as the one in Figure 4, it could yield a higher

sensitivity (80.6%) and overall accuracy (75.2%) rate as compared to other sub or partially completed models.

Therefore to adopt the Practice-based evidence approach, similar data mining methods such as the one mentioned above, can be applied to the extracted data at the business intelligence tool end (refer to Figure 4). Next, the findings from the analysis can be pushed in real-time to healthcare professionals through the decision support system, providing them with additional analytical and statistical information that can be applied in their decision-making process. Together with their inherent knowledge and experience, the additional findings can support healthcare professionals identify new undiagnosed diabetics or provide medication recommendation as illustrated in the PBE e-health scenario. Consequently, the decisions taken by healthcare professionals are captured again in patients' health records, be it a prescription order, laboratory test order, treatment provided or diagnosis. Thus, it further reinforces the evidence captured in EHR and the cycle of practice-based evidence is repeated, improving future decision-making processes.

Furthermore, leveraging on EHR as sources of clinical evidence not only improves the quality of decision-making but also uncovers new findings that may have taken a longer time to be discovered. As demands for effective and cost-efficient care increases, the approach of PBE not only assists healthcare professionals with making quality decisions, but also directs patient-centered care and achieves it in real-time. It will surely improve the quality of care when healthcare professionals are more equipped to make better decisions.

IV. Conclusion And Future works

The theory of Practice-based evidence aims at improving the quality of decision-making by healthcare professionals through the use of practical clinical evidence. It also complements the Evidence-based practice approach by providing patient-centered clinical evidence. Such clinical evidence may provide healthcare professionals with alternative information that allows them to make a more informed decision. As we continually develop further proper designs and implementations, the Practice-based evidence approach has the potential to provide solutions to complex and complicated healthcare situations at a much faster rate.

Currently, we are working on evaluating the conceptual theory of Practice-based evidence. At present, the evaluation process will make use of both simulated and actual patient health data sets as sources of practical clinical evidence through a series of data mining and data analytics algorithms to achieve the best result that can be adopted to improve and assist decision-making by healthcare professionals. Based on the findings from the evaluation, it will provide us with the knowledge on how to have the approach implemented in an actual clinical practice setting.

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